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# APPLICATION OF NOVEL NEUTRON CORRELATION TECHNIQUES TO NUCLEAR MATERIAL MEASUREMENTS

Ken Sale

June 15, 2006

Proceedings of the Institute of Nuclear Materials Management 47th Annual Meeting

## Disclaimer

# APPLICATION OF NOVEL NEUTRON CORRELATION TECHNIQUES TO NUCLEAR MATERIAL MEASUREMENTS

Principle Author: Ken Sale, Lawrence Livermore National Laboratory, United States

**Abstract**

Confirmation of the fissile mass of a system containing plutonium can be done using neutron multiplicity techniques. This can be accomplished with a detector system that is smaller and less costly than a standard neutron multiplicity counter (NMC). Also the fissile mass of a uranium containing system can be confirmed by passive means. Recent work at Lawrence Livermore National Laboratory[1] has demonstrated that simple slab neutron detectors and a novel approach to data acquisition and analysis can be used to make an accurate measurement of the mass of fissile materials. Purely passive measurement of kilogram quantities of highly enriched uranium (HEU) have also been shown to be feasible. In this paper we discuss calculational tools for assessing the application of these techniques to fissile material transparency regimes. The tools required to adequately model the correlations and their application will be discussed.

**Introduction**

The fission chains in a multiplying system are nearly the only source of neutrons with non-Poisson counting statistics. The "clumpiness" in time that can be observed in neutrons (or gamma-rays) from a multiplying system can be analyzed to infer properties of the system. This is the basis of neutron multiplicity counters (NMC). Based on experimental, theoretical, and computational work that has been done at LLNL we believe that passive systems, using detectors that are considerably smaller than those used in a classic NMC, can be effectively applied to support nuclear materials transparency. Progress in the development of modeling tools for predicting the performance of such a system are described here.

**Modeling Basis**

The radiation transport code our efforts are based on is COG. The key capability of COG that drove this choice was the facility for using user-written source and detector (tally in MCNP terms) routines which are loaded at run time. This allows special purpose source and detector capabilities to be implemented without the need to rebuild COG (or even have access to source code)[2]. No modifications to COG have been made, everything described here is accomplished using standard COG (which is available through RSICC).

Schematically, the way the user defined source works is that whenever COG needs a source particle the user's routine is called and a single source particle is requested. To simulate a spontaneous fission event as a particle source the source routine generates all the neutrons from a fission event and hands them to COG one at a time, doing all the bookkeeping needed. After the entire history of a source particle and all its progeny has been determined the user's detector routine is called and has access to the history generated by the single source particle. We gather up all the results from the single particles of a fission source event and report the combined information. In concept, COG always believes it is simply dealing with simple single particle sources, the bookkeeping and particle history aggregation to recover the complete fission history is accomplished by the user defined source and detector "cooperating behind COG's back."

The user defined source and detector routines are written in FORTRAN. These routines produce a text file of detected neutron events. So far the neutron detection mechanism that has been modeled is that of a $^{3}$He detector. Every fission source event and each $^{3}$He(p,n)$^{3}$H event (time and deposited energy) is logged in the output file.

Post-processing of the event files is done using open source tools. The post-processors are written in Python[3] and use several open source libraries including PythonCard[4], PyTables[5] and NumPy[6]. Implementing the post-processing algorithms in Python makes truly complete cross platform compatibility and availability possible. We intend to make the software being developed widely available.

The first stage of post-processing converts the text file from COG into a database of detections (time since the originating event and energy deposited) resulting from single fission source events. These are stored in HDF5 databases. The second stage mixes events from multiple sources, each according the waiting time distribution for a source with that fission rate, to create a time ordered list of all detection events. This combined file can then be analyzed.

**Fission Physics**

The physics model implemented for the fission source is based on the work of Terrell[7] for the fission neutron multiplicity and samples a (single) Watt spectrum for the fission neutron energy. It seems highly unsatisfactory to sample the same neutron energy spectrum, an average over all fission fragments, independent of the number of neutrons produced, however there is good data for the averaged spectrum while the data for a more complete treatment of the ν-dependant energy spectra are lacking. So far descriptions of spontaneous fission of $^{238}$U and $^{240}$Pu are available. We intend to develop descriptions for cosmic ray spallation and muon induced fission as these processes may be an important, correlated background, and may be significant for U systems. Subsequent to the initial fission source event all particles transported are handled by COG. The neutron data set for transport is the ENDF B6/R7 set. Other data sets available include ENDL-90 well as the data set used by TART[8].

## Analysis Methods

There are several possible ways to analyze the time sequence data to investigate the statistical properties of the fission chains. One very straight forward scheme is to measure the frequency of observing some number of counts, n, in a time window to get the count probability distribution $p_n(\tau)$ for each value of n as a function of the width of the counting time window, $\tau$. A second approach is to compute the two-point correlation function, that is the probability of detecting a second neutron within some time window, $\tau$ at a time t after the first neutron was detected. An approach that fairly directly addresses the fission chain properties is to calculate the Feynman combinatorial moments of the time sequence of detections. We have implemented each of these approaches.

## First Results

The simplest case test is a source with a fixed multiplicity, $\nu$, and energy. As a simple test $\nu = 1$ is chosen. If everything is working correctly the process is purely Poisson and all the statistical properties are determined by the rate parameter (see Figure 1). To ensure that a fission-like source is treated properly the $\nu = 1$ case is contrasted with a $\nu = 4$ example with the same average total neutron source rate. These results are shown in Figure 2.

## Conclusions and Future Plans

We have developed and demonstrated a calculational capability for simulating and analyzing multiplicity data. The capability includes sampling from simple test cases (fixed neutron energy and multiplicity) and models of fission. Detection data from any combination of sources can be merged and analyzed. These capabilities are based on the transport code COG which is widely available through RSICC. We expect to release the source code for the user defined source and detector modules and the post-processing and analysis codes when they have undergone reasonable validation. We also hope to include cosmic ray spallation and muon-induced fission models in the source module. We will also work to speed up the post processing algorithms which at the present time are implemented in the simplest, most naïve, serial-processing way.

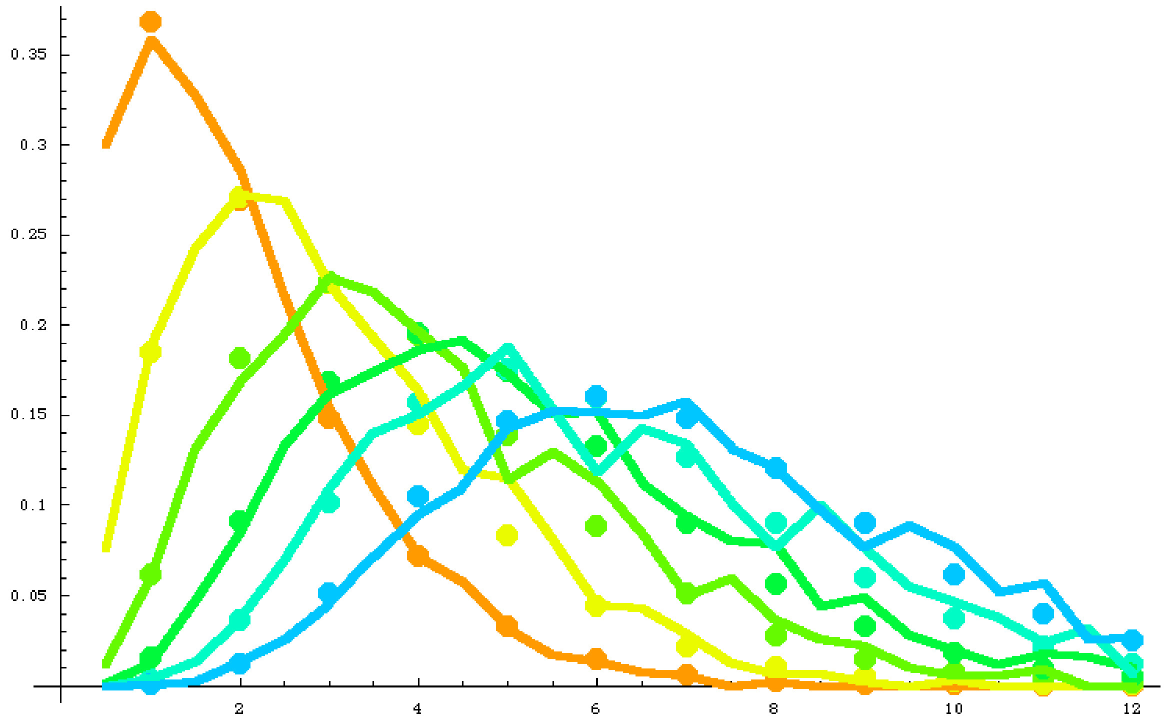


**Figure 1** Multiplicity probabilities for the ν = 1 case with the expected values for an uncorrelated (purely Poisson) process. As expected multiplicities for simple random source of single neutrons are accurately predicted by a Poisson model.

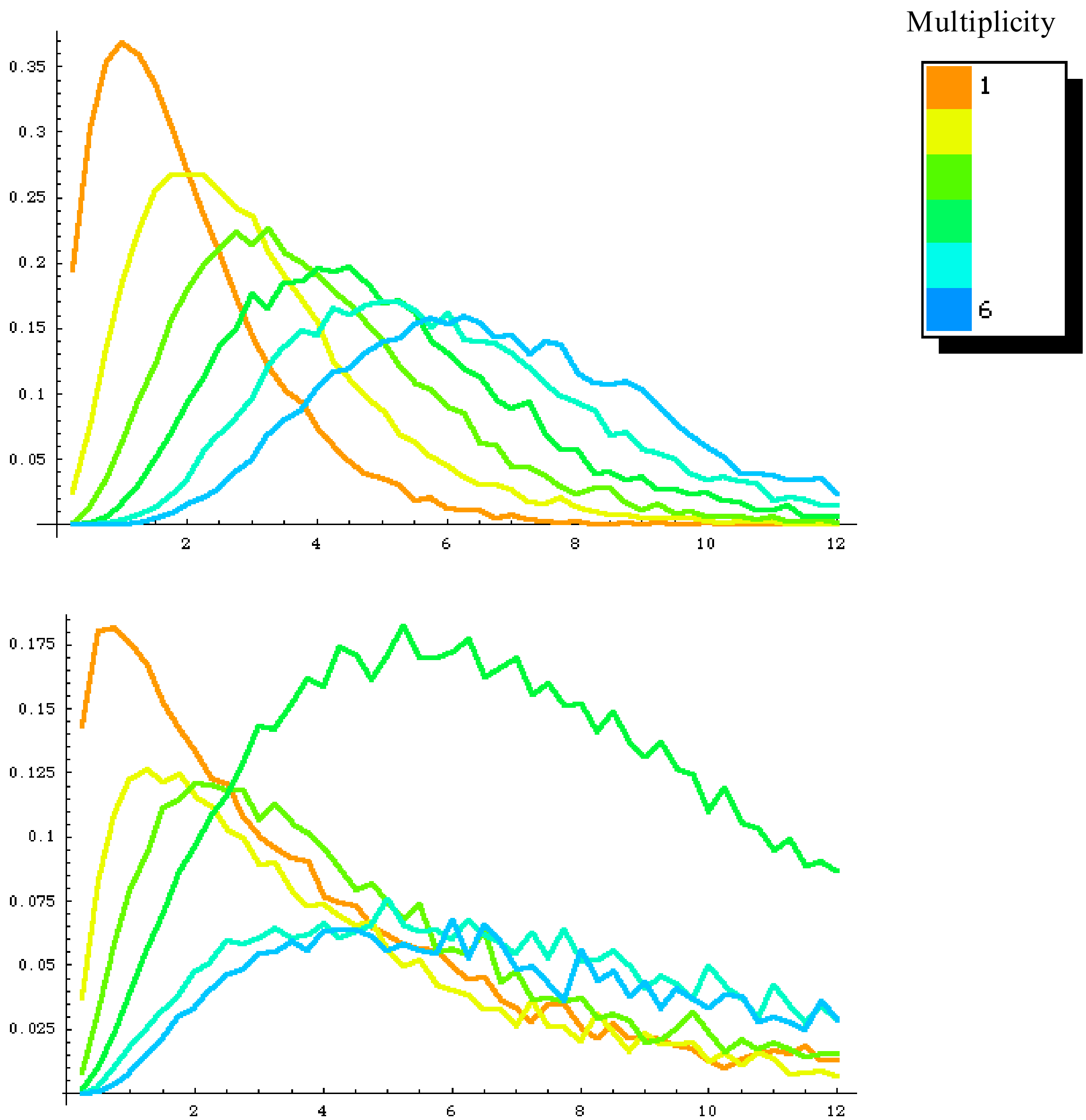


**Figure 2** Probability for detecting 1 to 6 neutrons as a function of the time window width for a $\nu = 1$ (upper) and a $\nu = 4$ source (lower). The lower plot demonstrates an excess of four-neutron "clumps" in the time series data.

**Acknowledgements**

The author is grateful to Mike Frank and Neal Snyderman of LLNL for very helpful discussions and to the DOE Office of Dismantlement and Transparency (NA-241) for sponsoring this work.

**Disclamer**

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**Auspices**

This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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[1] Statistical Theory of Fission Chains and Generalized Poisson Neutron Counting Distributions, Manoj K. Prasad and Neal J. Snyderman, UCRL_ID_148010

[2] COG Version10: Multiparticle Monte Carlo Code System for Shielding and Criticality Use. available through RSICC (http://www-rsicc.ornl.gov/) as code package CCC_724

[3] http://www.python.org/

[4] http://www.pythoncard.org/

[5] http://www.pytables.org

[6] http://numeric.scipy.org/

[7] James Terrell, Phys. Rev. **108**, 783 (1957)

[8] Dermott E. Cullen, http://www.llnl.gov/cullen1/mc.htm